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Computer-aided characteristics prediction of complex technical systems operation processes

Keywords

operation processes, prediction, complex systems, transport system

Abstract

In the paper, the procedures of the prediction of complex technical system operation process' characteristics are described. Furthermore, the computer program for prediction of the operations processes capabilities with description are presented. As the application of this computer program, the characteristics' prediction of the port oil transportation technical system operation process is shown.

1. Introduction

The complex technical systems consist of a large number of subsystems and components. Furthermore, the operation processes of this class of the systems are complicated. Thus, there is the problem with inability to accurately describe the transitions between states. Changes of the complex technical systems operation states imply the changes of reliability structures of these systems and sometimes even a change the reliability characteristics of their components. In this case, the semi-Markov approach [1], [2], [4] is a good description of complex technical systems operation processes [1].

2. The complex technical systems operation processes

According to [5], we assume that the system during its operation process is taking $v, v \in N$, different operation states. Further, we define the system operation process $Z(t)$, $t \in <0,+\infty)$, with discrete operation states from the set of states $Z = \{z_1, z_2, \ldots, z_v\}$. Moreover, we assume that the system operation process $Z(t)$ is semi-Markov [1], [2], [4] with the conditional sojourn times θ_{bl} at the operation states z_b when its next operation state is z_l, $b, l = 1,2,...,v$, $b \neq l$.

2.1. Input preliminary parameters of complex technical system operation processes

Under general assumptions, to predict the basic characteristics of semi-Markov model [1], [2], [4] of the complex technical system operation processes, we should define its necessary following input preliminary parameters [5]:

- the duration time θ of the system operation process,
- the number v of the operation states of the system operation process,
- the vector of probabilities $[p_b(0)]_{1 \times v}$ of the system operation process initial operation states, where $p_b(0) = P(Z(0) = z_b)$ for $b = 1,2,...,v$,
- the matrix of probabilities $[p_{bl}]_{v \times v}$ of the system operation process transitions between the operation states, where $p_{bb} = 0$ for $b = 1,2,...,v$,

- the mean values $M_{bl} = E[\theta_{bl}]$ of the conditional sojourn times θ_{bl} at the operation states z_b when its next operation state is z_l, $b, l = 1,2,...,v$, $b \neq l$.

2.2. Prediction of complex technical system operation processes

When the basic parameters, describe in Section 2.1 are given and from the formula for total probability, the mean values of the unconditional sojourn times θ_b, $b = 1,2,...,v$, of the system operation process at the operation states z_b, $b = 1,2,...,v$, are given by [5]:

$$M_b = E[\theta_b] = \sum_{l=1}^{v} p_{bl} M_{bl} \, , \; b = 1,2,...,v, \qquad (1)$$

where p_{bl} are the input probabilities of transitiens between the operation states defined as the matrix of probabilities and M_{bl} are the input conditional mean values of the conditional sojourn times θ_{bl}, defined in [1], [6].

The limit values of the transient probabilities at the particular operation states $p_b(t) = P(Z(t) = z_b)$, $t \in <0,+\infty)$, $b = 1,2,...,v$, are given by

$$p_b = \frac{\pi_b M_b}{\sum_{l=1}^{v} \pi_l M_l}, \; b = 1,2,...,v, \qquad (2)$$

where M_b, $b = 1,2,...,v$, are given by (1), while the steady probabilities π_b of the vector $[\pi_b]_{1xv}$ satisfy the system of equations

$$\begin{cases} [\pi_b] = [\pi_b][p_{bl}] \\ \sum_{l=1}^{v} \pi_l = 1. \end{cases} \qquad (3)$$

Other practically interesting characteristics of the system operation process possible to obtain are its total sojourn times $\hat{\theta}_b$ in the particular operation states z_b, $b = 1,2,...,v$, in the fixed operation time θ. It is well known [5] that the system operation process total sojourn times $\hat{\theta}_b$ in the particular operation states z_b, for sufficiently large operation time θ have approximately normal distribution with the expected value given by

$$E[\hat{\theta}_b] = p_b \theta, \; b = 1,2,...,v, \qquad (4)$$

where p_b are given by (2).

3. Description of the computer program for prediction of the complex technical systems operation processes

The presented computer program is based on methods of identification the complex technical system operation processes presented in Section 2.2 and given in [5]. The computer program is written in Java language with using SSJ V2.1.3 library. The SSJ library is a Java library, developed in the Department d'Informatique et de Recherche Operationelle (DIRO) at the Universite de Montreal, gives the support of stochastic simulations. The on-line documentation of SSJ can be found at the website http://www.iro.umontreal.ca/~simardr/ssj/indexe.html..

This program is composed of one panel with two parts: "INPUT" and "OUTPUT". First part is used to read the input preliminary parameters of system operation process, i.e.:

– the number v the operation states of the system operation process,
– the duration time θ of the system operation process,
– the matrix of probabilities of the system operation process transitions between the operation states,
– the matrix of the mean values of the conditional sojourn times θ_{bl} at the operation states z_b when its next operation state is z_l.

When the reading data is finished, the computer program automatically predicts the characteristics of the system operations process. Then the following results of the program are show in the section "OUTPUT":

– the unconditional mean values $M_b = E[\theta_b]$, $b = 1,2,...,v$, of sojourn times θ_b, $b = 1,2,...,v$, at the particular operation states,
– the limit values of the transient probabilities p_b, $b = 1,2,...,v$, at the particular operational states,
– the expected value $E[\hat{\theta}_b] = p_b \theta$, $b = 1,2,...,v$, of total sojourn times $\hat{\theta}_b$ in the particular operation states z_b, $b = 1,2,...,v$, in the fixed operation time θ.

4. Computer-aided prediction of unknown characteristics of operation process of the the port oil transportation technical system operation process

We consider the operation process of the port oil transportation system [3]. It is the main part of the Oil Terminal in Dębogórze that is designated for the reception from ships, the storage and sending by carriages or by cars the oil products such like petrol and oil. It is also designated for receiving from carriages or cars, the storage and loading the tankers with oil products.

The considered terminal is composed of three parts *A*, *B* and *C*, linked by the piping transportation systems with the pier. The unloading of tankers is performed at the pier placed in the Port of Gdynia. The pier is connected with terminal part *A* through the transportation subsystem S_1 built of two piping lines composed of steel pipe segments with diameter of 600 mm. In the part *A* there is a supporting station fortifying tankers pumps and making possible further transport of oil by the subsystem S_2 to the terminal part *B*. The subsystem S_2 is built of two piping lines composed of steel pipe segments of the diameter 600 mm. The terminal part *B* is connected with the terminal part *C* by the subsystem S_3. The subsystem S_3 is built of one piping line composed of steel pipe segments of the diameter 500 mm and two piping lines composed of steel pipe segments of diameter 350 mm. The terminal part *C* is designated for the loading the rail cisterns with oil products and for the wagon sending to the railway station of the Port of Gdynia and further to the interior of the country.

The oil pipeline system consists three subsystems S_1, S_2, S_3:

- the subsystem S_1 composed of two identical pipelines, each composed of 178 pipe segments of length 12m and two valves,

- the subsystem S_2 composed of two identical pipelines, each composed of 717 pipe segments of length 12m and two valves,

- the subsystem S_3 composed of three different pipelines, each composed of 360 pipe segments of either 10 m or 7,5 m length and two valves.

Taking into account the expert opinion on the operation process of the considered port oil pipeline transportation system we fix the number $\nu = 7$ of the pipeline system operation process states and we distinguish the following as its seven operation states:

- an operation state $z_1 -$ transport of one kind of medium from the terminal part B to part C using two out of three pipelines in subsystem S_3,
- an operation state $z_2 -$ transport of one kind of medium from the terminal part C (from carriages) to part B using one out of three pipelines in subsystem S_3,
- an operation state $z_3 -$ transport of one kind of medium from the terminal part B through part A to pier using one out of two pipelines in subsystem S_2 and one out of two pipelines in subsystem S_1,
- an operation state $z_4 -$ transport of two kinds of medium from the pier through parts A and B to part C using one out of two pipelines in subsystem S_1, one out of two pipelines in subsystem S_2 and two out of three pipelines in subsystem S_3,
- an operation state $z_5 -$ transport of one kind of medium from the pier through part A to B using one out of two pipelines in subsystem S_1 and one out of two pipelines in subsystem S_2,
- an operation state $z_6 -$ transport of one kind of medium from the terminal part B to C using two out of three pipelines in subsystem S_3, and simultaneously transport one kind of medium from the pier through part A to B using one out of two pipelines in parts S_1 and one out of two pipelines in subsystem S_2,
- an operation state $z_7 -$ transport of one kind of medium from the terminal part B to C using one out of three pipelines in part S_3, and simultaneously transport second kind of medium from the terminal part C to B using one out of three pipelines in part S_3.

Moreover, we fix that there are possible the transitions between all system operation states.

The input necessary parameters of the port oil piping transportation system operation process are as follows [3]:

- the oil piping system operation time is $\theta = 1$ year = 365 days,

- the number of the piping system operation states is $\nu = 7$,

- the initial probabilities $p_b(0)$, $b = 1,2,...,7,$ of the piping system operation process transients in the particular states z_b at the moment $t = 0$, are

$$[p(0)]_{1x7} = [0.34, 0.05, 0, 0, 0.23, 0.19, 0.19],$$

- the transition probabilities p_{bl}, $b, l = 1,2,...,7,$ of the piping transportation system operation process from the operation state z_b into the operation state z_l are

$$[p_{bl}]_{7x7} = \begin{bmatrix} 0 & 0.022 & 0.022 & 0 & 0.534 & 0.111 & 0.311 \\ 0.2 & 0 & 0 & 0 & 0 & 0 & 0.8 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0.488 & 0.023 & 0 & 0.023 & 0 & 0.233 & 0.233 \\ 0.095 & 0 & 0 & 0 & 0.667 & 0 & 0238 \\ 0.516 & 0.064 & 0 & 0 & 0.226 & 0.194 & 0 \end{bmatrix},$$

- the mean values of the conditional sojourn time of the system operation process in the particular operation states

$$M_{12} = 1920,\ M_{13} = 480,\ M_{15} = 1999.4,$$
$$M_{16} = 1250,\ M_{17} = 1129.6,\ M_{21} = 9960,$$
$$M_{27} = 810,\ M_{31} = 575,\ M_{47} = 380,$$
$$M_{51} = 874.7,\ M_{52} = 480,\ M_{54} = 300,$$
$$M_{56} = 436.3,\ M_{57} = 1042.5,\ M_{61} = 325,$$
$$M_{65} = 510.7,\ M_{67} = 438,\ M_{71} = 874.1,$$
$$M_{72} = 510,\ \ M_{75} = 2585.7,\ \ M_{76} = 2380.$$

As there are no realizations of conditional sojourn times θ_{14}, θ_{23}, θ_{24}, θ_{25}, θ_{26}, θ_{32}, θ_{34}, θ_{35}, θ_{36}, θ_{37}, θ_{41}, θ_{42}, θ_{43}, θ_{45}, θ_{46}, θ_{53}, θ_{62}, θ_{63}, θ_{64}, θ_{73} and θ_{74} it is impossible to estimate their conditional mean values M_{14}, M_{23}, M_{24}, M_{25}, M_{26}, M_{32}, M_{34}, M_{35}, M_{36}, M_{37}, M_{41}, M_{42}, M_{43}, M_{45}, M_{46}, M_{53}, M_{62}, M_{63}, M_{64}, M_{73}, M_{74}.

This data are loaded to the computer program and it is shown in its "INPUT" window (*Figure 1*).

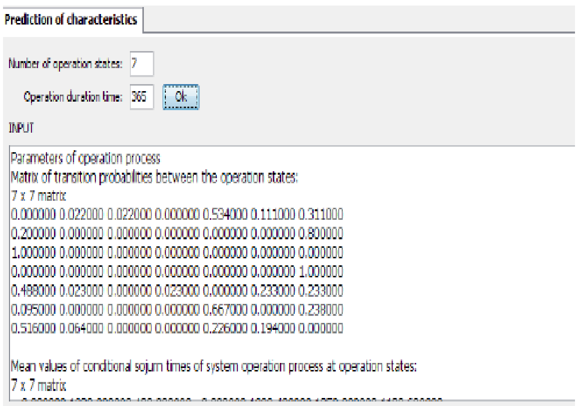

Figure 1. Basic parameters of the port oil transportation system operation process

After the basic input data, the following output characteristics are got as the results of computer program in "OUTPUT" for considered technical system operation process (*Figure 2*):
- the unconditional mean sojourn times in the particular operation states,
- the limit values p_b of the transient probabilities at the operational states z_b,
- the expected values of the total sojourn times $\hat{\theta}_b$, $b = 1,2,...,7$, of the system operation process in particular operation states z_b, $b = 1,2,...,7$, during the fixed operation time.

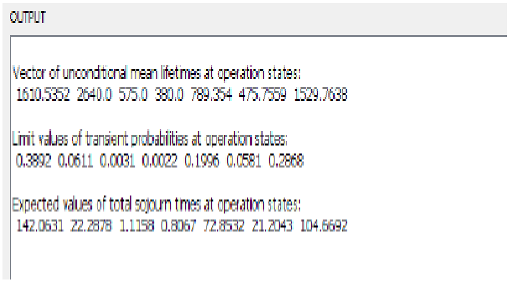

Figure 2. Characteristics of the port oil transportation system operation process

After receiving the final results, they can be printed and then quit the program or restart.

5. Conclusion

The presented computer program is used for prediction of the unknown characteristics of complex technical systems operation processes. It is based on methods and algorithms given in [5]. This program allows us to automatically find the unknown characteristics of complex technical systems operation processes. In the article presented program have been used to prognosis unknown characteristics of the port oil transportation system operation process.

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